RENEWABLE ENERGY SOURCES

An energy source is called renewable if it can be renewed and sustained without any depletion and any significant effect on the environment. It is also called an alternative, sustainable, or green energy source. Fossil fuels such as coal, oil, and natural gas, on the other hand, are not renewable, and they are depleted by use. They also emit harmful pollutants and greenhouse gases.

Renewable energy sources occur in nature which are regenerative or inexhaustible like solar energy, wind energy, hydropower, geothermal, biomass, tidal and wave energy. Most of these alternative sources are the manifestation of solar energy as shown in Figure-1 below.

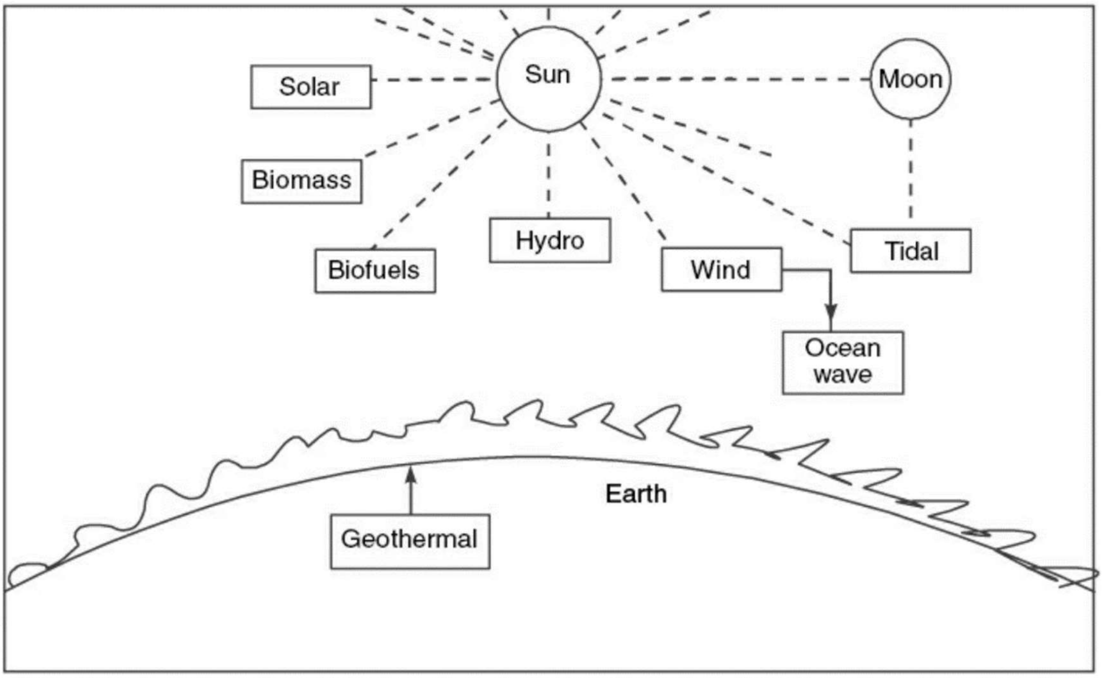


Figure-1 Renewable sources of energy

Such resources are safe for the environment and generate energy without the emissions and harmful pollutants associated with fossil fuels. Energy sources from the ocean, including ocean thermal energy conversion (OTEC), wave, and tidal, are currently not economical and the technologies are still in the experimental and developmental stage.

The best-known renewable source is solar energy. Although solar energy is sufficient to meet the entire energy needs of the world, currently it is not used as extensively as fossil fuels because of the low concentration of solar energy on earth and the relatively high capital cost of harnessing it. The conversion of kinetic energy of wind into electricity via wind turbines represents wind energy, and it is one of the fastest-growing renewables as wind turbines are being installed all over the world. The collection of river water in large dams at some elevation and then directing the collected water into a hydraulic turbine is the common method of converting water energy into electricity. Hydro or water energy represents the greatest amount of renewable electricity production, and it supplies most of the electricity needs of some countries.

Geothermal energy refers to the heat of the earth. High-temperature underground geothermal fluid found in some locations is extracted, and the energy of the geothermal fluid is converted to electricity or heat. Geothermal energy conversion is one of the most mature renewable energy technologies. Geothermal energy is mostly used for electricity generation and district heating. Organic renewable energy is referred to as biomass, and a variety of sources (agriculture, forest, residues, crops, etc.) can be used to produce biomass energy. Biomass is becoming more popular with the help of the variety of available sources.

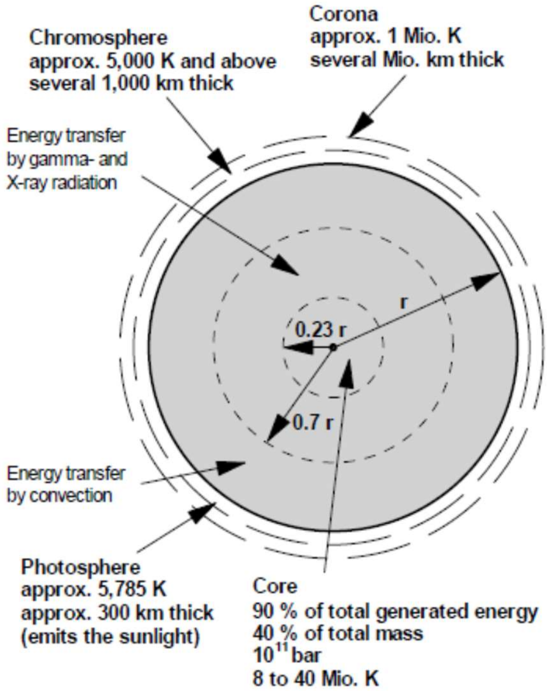
Wave and tidal energies are renewable energy sources, and they are usually considered as part of ocean energy since they are available mostly in oceans. Thermal energy of oceans due to absorption of solar energy by ocean surfaces is also considered as part of ocean energy, and this energy can be utilized using the OTEC system. Wave and tidal energies are mechanical forms of ocean energy since they represent potential and kinetic energies of ocean water.

Hydrogen is an energy carrier that can be used to store renewable electricity. It is still a developing technology, and many research activities are under way to make it viable. Fuel cells convert chemical energy of fuels (e.g., hydrogen) into electricity directly without a highly irreversible combustion process, and it is more efficient than combustion-based conversion to electricity.

All renewable energy sources can be used to produce useful energy in the form of electricity and some renewables can also produce thermal energy for heating and cooling applications. Wind and water energies are converted to electricity only while solar, biomass, and geothermal can be converted to both electricity and thermal energy (i.e., heat). The energy flows of the earth are fed from various sources described above. Solar energy has a share of more than 99.9 % of all the energy converted on earth. The solar radiation incident on the earth is weakened within the atmosphere and partially converted into other energy forms (e.g. wind, hydro power). Therefore, the structure and the main attributes of the earth's atmosphere will also be described in more detail, followed by balancing the global energy flows.

Solar Energy

The sun is the central body of our planetary system; it is the star closest to the earth. Its schematic structure with its main parameters is shown in Fig. 2.



Parameters

Diameter	1,390,000 km (approx. 109 times the diameter of the earth)
Mean density	1.4 g/cm^3
Core density	80 bis 100 g/cm^3
Mass	2 10^{33} g (approx. 330,000 times the mass of the earth)
Gravitational acceleration	approx. 275 m/s (approx. 28 times earth gravity)
Components	75 % hydrogen (H_2) 23 % helium (He) 2 % other components
Condition	gaseous

Figure 2 Schematic structure and main parameters of the Sun

Accordingly, the nucleus has temperatures of approximately 15 Mio. K. Energy is released by nuclear fusion where hydrogen is melted to helium. The resulting mass loss is converted into energy E. According to Einstein, it can be calculated multiplying mass m and the square of the speed of light v_c (Equation (1)). Approximately 650 Mio. t/s of hydrogen are converted into approximately

646 Mio. t/s of helium. The difference of approximately 4 Mio. t/s is converted into energy.

$$E = mv_c^2 \tag{1}$$

The energy released within the nucleus of the sun is initially transported by radiation to approximately 0.7 times the solar radius. Further transport to the surface of the sun takes place through convection. Afterwards, the energy is released into space. This energy stream released by the sun is differentiated as radiation of matter on the one hand and electromagnetic radiation on the other hand. The radiation of matter consists of protons and electrons released by the sun at a speed of approximately 500 km/s. However, only a few of these electrically charged particles reach the earth's surface, as most of them are deflected by the terrestrial magnetic field. This is of particular importance for life on earth, as this harsh matter radiation would not allow organic life in its current form. Electromagnetic radiation mainly released by the photosphere (Fig. 1) covers the entire frequency from short-wave to long-wave radiation. This type of solar radiation is approximately equivalent to that of a black body. The radiant flux density of the sun M_S can be derived from the temperature within the photosphere (approximately 5,785 K), the degree of emission, and the Stefan-Boltzmann-constant; it is approximately 63.5 10^6 W/m^2.

The radiant flux density of the sun decreases – if losses are not considered – with the square of the distance travelled. Thus, the radiant flux density at the outer rim of the earth atmosphere E_{SC} can be calculated according to Equation (2).

$$E_{sc} = \frac{M_S \pi d_S^2}{\pi (2L_{ES})^2} \qquad (2)$$

If the diameter of the sun d_S is assumed up to the photosphere (approximately 1.39 x 10^9 m) and a mean distance between the sun and the earth (L_{ES}) of approximately 1.5 x 10^{11} m is taken into consideration, a radiant flux density of approximately 1,370 W/m^2 can be calculated at the top rim of the earth atmosphere. This mean value is called the solar constant. Over several years it varies less than 0.1 % due to a fluctuation in solar activity.

The solar radiation incident on the atmospheric rim throughout the course of the year is nevertheless characterised by seasonal variations. They are caused by the elliptical orbit, where the earth moves around the sun during the course of one year (Fig. 3). This changes the distance between the two celestial bodies. And this distance variation leads to a fluctuation in the radiation incident on the atmospheric rim; this results in the course of the solar constants shown in Fig. 4

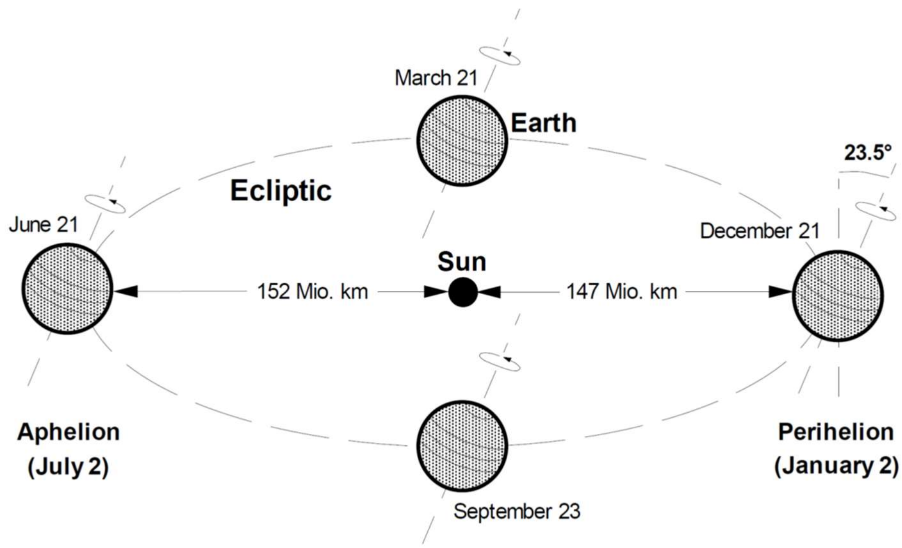


Figure 3 Elliptical orbit of the earth around the sun

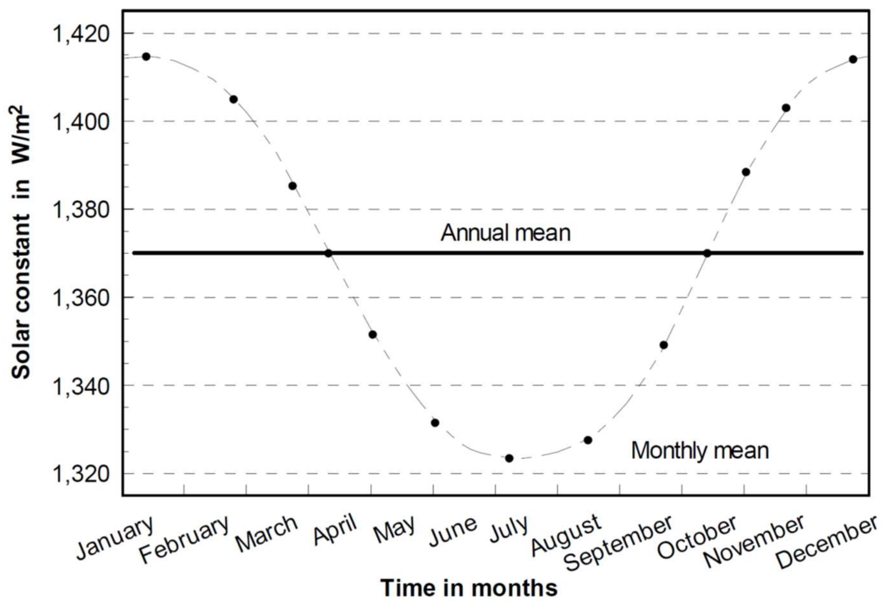


Figure 4 Solar constant in the course of one year

In spite of the higher radiation intensity at the outer atmospheric rim, on average there are significantly lower temperatures on the Northern hemisphere during the winter than during the summer. The reason for this is that the rotation axis of the earth forms an angle of 66.5° with the orbital plane (Fig. 3). Thus during the winter the Southern hemisphere is facing the sun more than the Northern hemisphere. This leads to a higher solar altitude and longer periods of sunshine.

On the Northern hemisphere, however, the solar radiation incidents at a generally flatter angle during this season with comparably short days. Areas close to the North Pole are sometimes not facing the sun throughout the entire day. During winter solstice, all places between 66.5° N and the pole have "eternal polar night". Correspondingly, on the Southern hemisphere the sun never disappears below the horizon south of 66.5° S ("midnight sun").

As the earth continues its orbit around the sun, its relative position changes. For the Northern hemisphere the sun starts to rise higher and higher, whereas the midday altitudes get increasingly lower on the Southern hemisphere. On March, 21st, solar radiation incidents on both poles. The Northern hemisphere is now more sun-facing, i.e. the mean solar position above the horizon gets increasingly higher. This continues until summer solstice (June, 21st), when the midnight sun then lights up the North Pole areas, and the Antarctic region sinks into "eternal night".

Due to these interrelations, and thus, primarily due to the angle of the earth axis towards the ecliptic, the solar radiation in different regions of this earth is subject to significant seasonal fluctuations.

Geothermal energy

The earth is a great reservoir of heat energy in the form of molten interior. Surface manifestation of this heat energy is indicated by hot water springs and geysers discovered at several places. Heat can be experienced from the temperature rise of the earth’s crust with increasing depth below the surface. Radial temperature gradient increases proportionally to depth at a rate of about 30°C per km. At a depth of 3–4 km, water bubbles up; while at a depth of 10–15 km the earth’s interior is as hot as 1000° to 1200°C. The core of the earth consists of a liquid rock known as ‘Magma’ having a temperature of about 4000°C.

This geothermal heat is transferred to the underground reservoir of water which also circulates under the earth’s crust. Its heat dissipates into the atmosphere as warm water and the steam vents up through the fissures in the ground as hot springs and geysers. Limitless heat content in magma plus the heat generated by radioactive decay of unstable elements such as K_{40}, Th_{232} and U_{235} which are abundant in the earth’s crust are forms of geothermal energy and considered as a renewable energy resource.

The energy flowing from the interior of the earth to its surface is fed by three different sources. On the one hand this is the energy stored in the interior of the earth resulting from the gravitational energy generated during the formation of the earth. The primordial heat that had even existed before that time is added as a second source. Thirdly, the process of decay of radioactive isotopes in the earth (in particular in the earth’s crust) releases heat. Due to the generally low heat conductivity of rocks, this heat resulting from these three sources is to a large extent still stored in the earth.

The formation of the earth took place approximately 4.5 Billion years ago. It was a step-by-step accumulation of matter (rocks, gases, dust) within an existing fog.

This process started off at low temperatures, which changed due to the increasing mechanical force of the matter amassing. During this aggregation of matter, gravitational energy was probably converted almost entirely into heat. Towards the end of this accumulation of mass, after approximately 200 Mio. years, the top level of the earth had melted. Due to this melting process, a large amount of the released heat was emitted into space again. In spite of all uncertainties about the accumulation of mass and the energy emission during this phase, the energy that remained in the earth during this phase was between 15 and 35 x 10^{30} J. The smaller value reflects a cold to warm primordial earth, the higher value a warm to hot primordial earth.

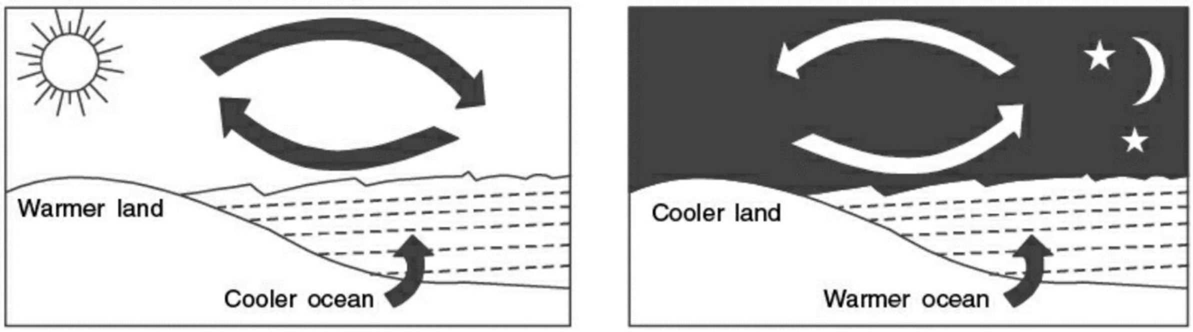
The earth contains radioactive elements (i.e. uranium (U^{238}, U^{235}), thorium (Th^{232}), potassium (K^{40})). Due to radioactive decay processes, they release energy over a period of millions of years. The mass fraction of uranium or thorium in granite is, for example, approximately 20 ppm and in basalt 2.7 ppm. With the appropriate half-life, a released energy of approximately 5.55 MeV for a decay event and approximately 6 (thorium) or 8 (uranium) decay events until a stable condition is reached, an amount of heat of around 1 J/(g a) is generated. This result, for example, in a radiogenic heat production efficiency of approximately 2.5 µW/m^3 in granite rock and of approximately 0.5 µW/m^3 in basalt rock.

The decay of such natural, long-living isotopes in the earth permanently generates heat. The involved isotopes in the near-surface layers of the earth are mainly enriched in the continental earth crust. Due to such radioactive decay processes, the earth has received around 7 1030 J of radiogenic heat since its formation. The potential radiogenic heat of still existing radioactive isotopes is approximately 12 x 10^{30} J. These figures are rather vague as little is known about the distribution of radioactive isotopes in the interior of the earth.

The currently available heat resulting from the earth's formation, respectively the primordial heat, as well as the heat already released to date and the heat attributable to the further decay of radioactive isotopes, all result in a total heat of the earth between 12 and 24 1030 J; in the exterior earth crust up to a depth of 10,000 m this amounts to approximately 1026 J. This energy potential is equal to the solar radiation incident on the earth in the course of many millions of years.

Wind Energy

Wind is air in motion and it derives energy from solar radiation. About 2% of the total solar flux that reaches the earth's surface is transformed into wind energy due to uneven heating of the atmosphere. During daytime, the air over the land mass heats up faster than the air over the oceans. Hot air expands and rises while cool air from oceans rushes to fill the space, creating local winds. At night the process is reversed as the air cools more rapidly over land than water over off-shore land, causing breeze, as shown in Figure 7.1. On a global scale low pressure exists near the Equator due to greater heating, causing winds to blow from subtropical belts towards the Equator. Also, the axial rotation of the earth induces a centrifugal force which throws equatorial air masses to the upper atmosphere, causing deflection of winds.



(a) (b)

Figure 5 (a) Wind from ocean to land during daytime, and (b) wind from land to ocean during night.

Wind energy is the first among renewable energy resources to become an economically viable source of power generation. Technological improvements have brought down the cost of wind power equal to that of coal-fired thermal power plant. India is blessed with many natural meteorological and topographical settings that are conducive to high speed winds suitable for power generation. Energy content in wind in different regions varies with latitudes, land sea dispositions, altitudes and seasons. In India, the prime factor governing the availability of wind energy at a particular site, is its geographical locations with reference to monsoon winds. A site is considered suitable where the wind speed is 18 km/h (5 m/s). Maximum wind energy can be tapped from a windy site by installing several wind turbines. The generated power is fed into a network. The whole system is called a ‘Wind Farm’.

A fundamental prerequisite for determining the feasibility of wind power generation is the availability of wind data at a given location. Three types of wind survey projects were undertaken during 1985 by MNRE with the Indian Institute of Tropical Meteorology, Bangalore.

- The first category was of a wind monitoring project to determine windy locations, using a 20-m mast and a microprocessor-based measuring instrument, to generate data for wind power development.
- The second category constituted wind mapping projects, based on 5-m mast, to establish wind regime in a given area of a state on an extensive basis.
- The third category projects covered complex terrain studies in hilly and mountainous regions to determine the wind flow in mountain passes and over undulated terrains.

Data collected from survey projects identified major windy sites in the coastal areas and also confirmed that several interior locations in Kerala, Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Karnataka, Maharashtra and Rajasthan have wind energy potential. The characteristic feature of large scale wind flow over India is the monsoon circulation. Wind flows are generally high from April to September and low during the rest of the period.

Meteorological data is used to evaluate the following:

1. To identify the areas where the highest wind speeds are available.

2. To measure Mean Annual Wind Speeds (MAWS) and their variability from year to year.

3. To record Monthly Mean Wind Speeds to indicate wind regimes for the area.
4. Measurement of Daily Mean Wind Speeds in order to understand their variation during different seasons of the year.

The wind climatology of India is determined by two extensive monsoon systems. Strong South-West monsoon winds during June to September over Western parts of Indian peninsula provide bulk wind energy potential. During November to February, North-West monsoon winds are relatively weaker and have lesser wind potential. For economic utilisation of wind power, a MAWS of at least 18 km/h is required.

The MAWS is an approximate index of the wind potential at a site. To evaluate the energy potential, another statistical parameter, i.e., mean monthly wind speed is required. It provides a comprehensive pattern about variability in wind energy during the course of the year. Windy areas of peninsular India experience annual maximum wind speeds (30–35 km/h) during May/June to September.

To gain further insight into the variability of winds, the daily mean wind speed is analysed which is the average of the winds during the 24 hours of the day. Higher winds suitable for power generation persist during June to September with some ups and downs which reveal the quasi-oscillatory character of monsoon current. A threshold speed of 15 km/h is the lowest speed needed to operate the wind electric generators.

Wind power is classified depending on resource potential at 30 m height and is given in Table-1

Resource potential	**Wind power density (W/m^2)**	**Wind speed (m/s)**
Fair	100 – 150	4.3 – 5.0
Good	150 – 200 200 – 300	5.0 – 5.5 5.5 – 6.3
Excellent	300 – 400 400 – 600 600 – 1000	6.3 – 7.0 7.0 – 8.2 8.2 – 10.1

The Centre for Wind Energy Technology (C-WET), Chennai, recently conducted a wind resource assessment programme in co-ordination with the state nodal agencies. Accordingly, an annual mean wind power density greater than 250 W/m2 at 50 m height, was recorded at 211 wind monitoring stations, covering Andaman and Nicobar Islands, Andhra Pradesh, Gujarat, Karnataka, Kerala, Lakshadweep, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Uttarakhand and West Bengal. India now ranks fifth in the world after USA China, Germany and Spain with an installed capacity of 11807 MW as on 31-3-2010.